Vehicle to Grid (V2G) to Support BART Electrical Demand

Eugene Nishinaga
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Invited Presentation for the
ZEV Technology Review
Requested by the Air Resources Board
September 26, 2006

Premise of This Presentation

- Electric energy storage technology (e.g. batteries, hydrogen) today still cannot compete with the gasoline tank
- Gasoline/Electric Hybrids can offer I.C.E. equivalent functionality and are gaining acceptance but are essentially gasoline cars
- Plug-in Hybrids are “more electric” but are costly
- V2G concept can help overcome cost barrier to both hybrid and non-hybrid electric drive vehicles

Discussion Topics

- Energy and Power Use at BART
- V2G Energy and Power Assessment
- V2G from the perspective of the car owner
- Effectiveness and Value to BART

BACK OF THE ENVELOPE CALCULATIONS FOR PI-HEV'S

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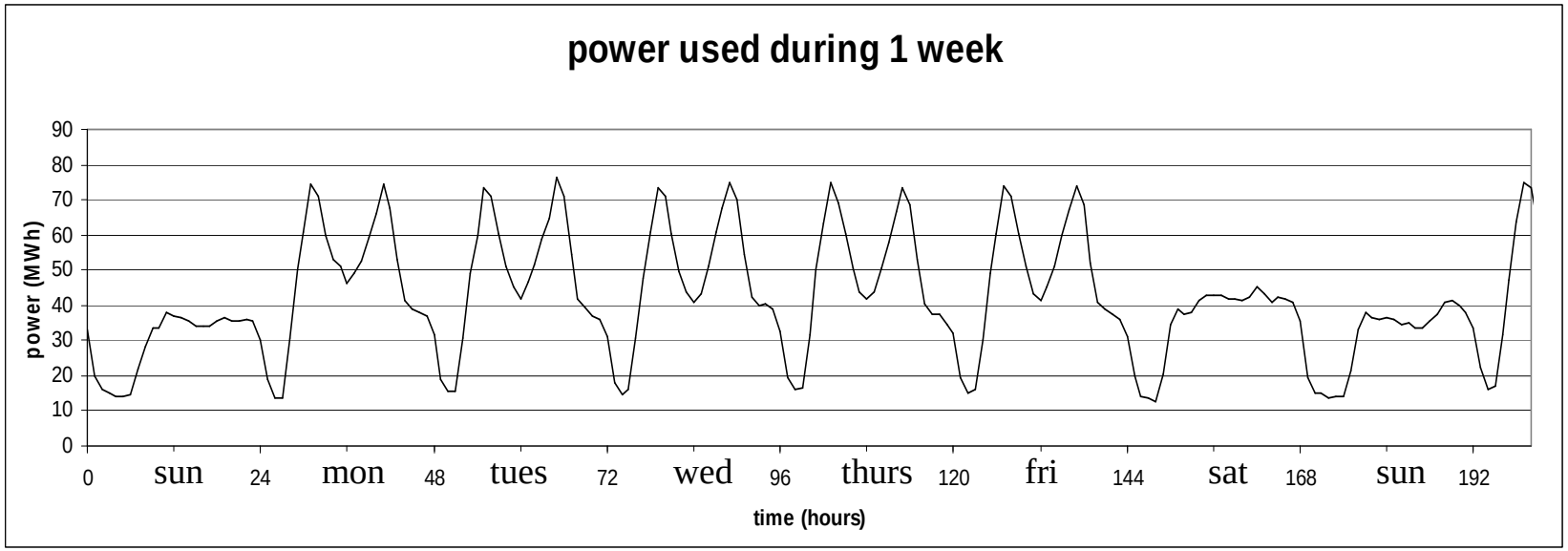
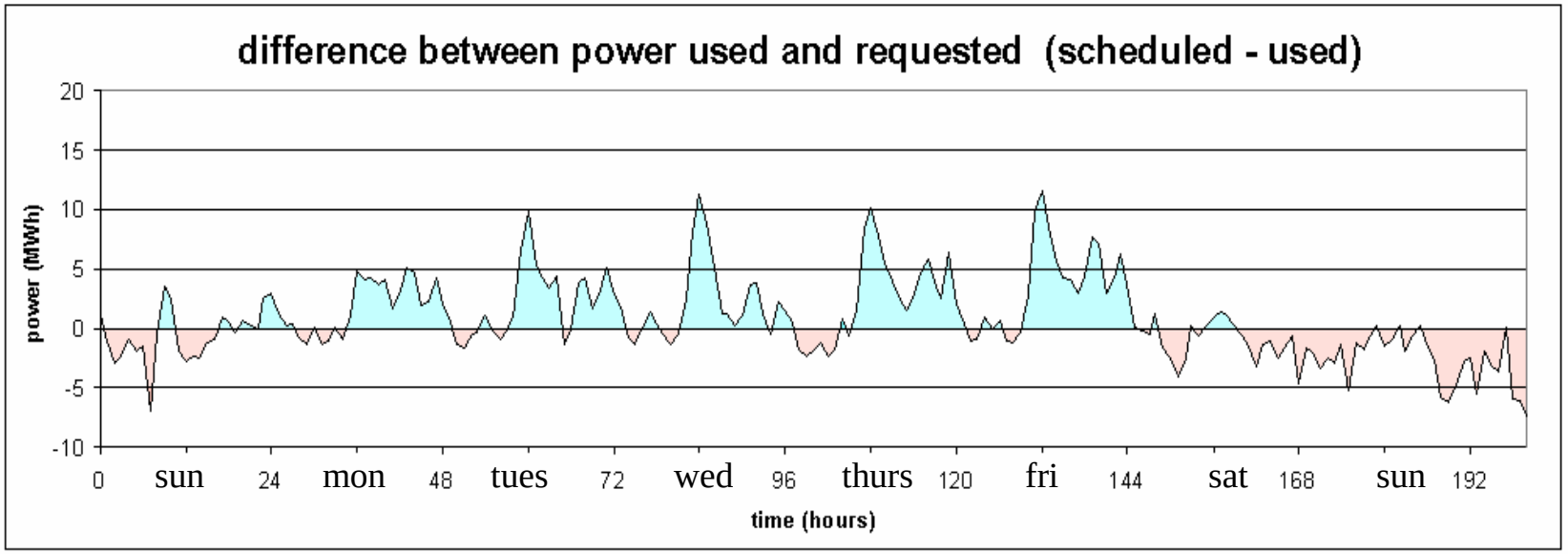
Power Purchasing at BART

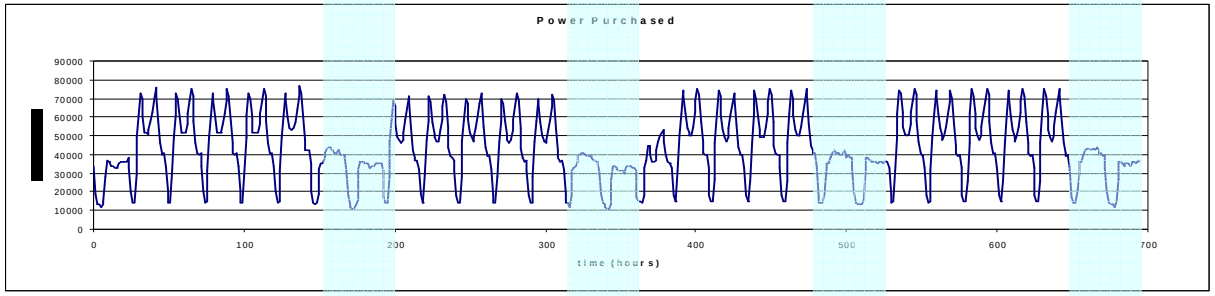
- Power must be scheduled in advance
- Cost of Scheduled Power: $0.06 / KWH
- Power scheduled but not used:
  - Paid for but not used
  - Fine of ~$0.10 / KWH during some parts of the day
- Cost of Excess Power: $0.20 / KWH

BART's Power Usage

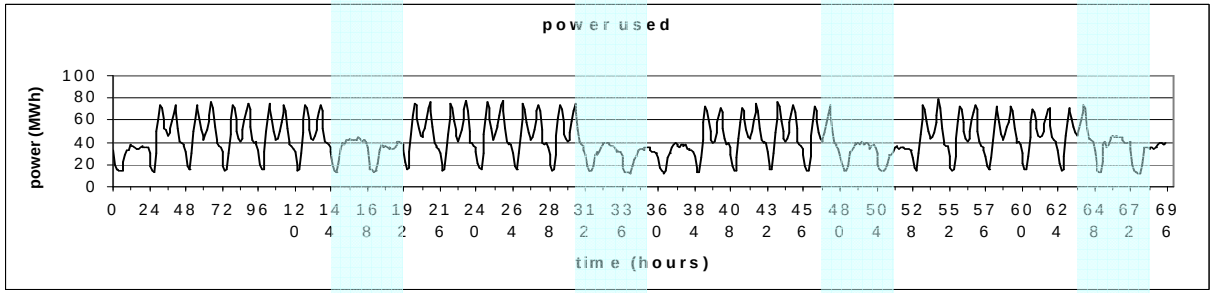




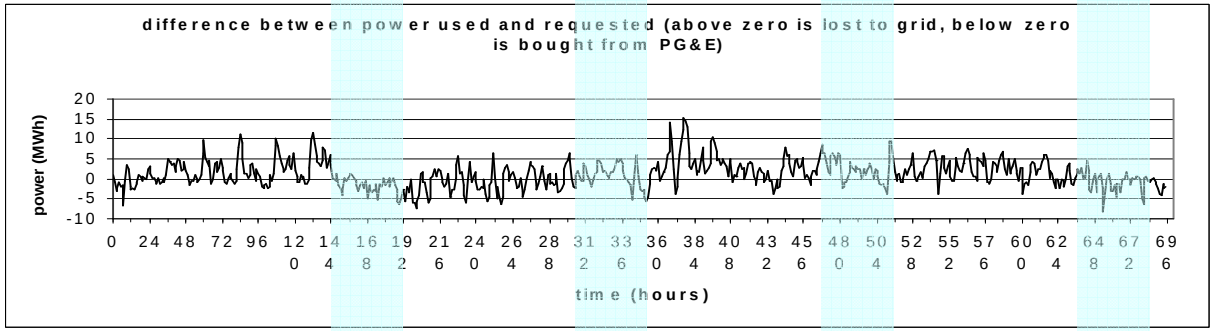
One Month of Data



Power Scheduled



Power Used



Scheduled - Used

Total Energy Purchased but not used ~ 1,389 MWH

Total Energy Purchased beyond scheduled ~ 517 MWH

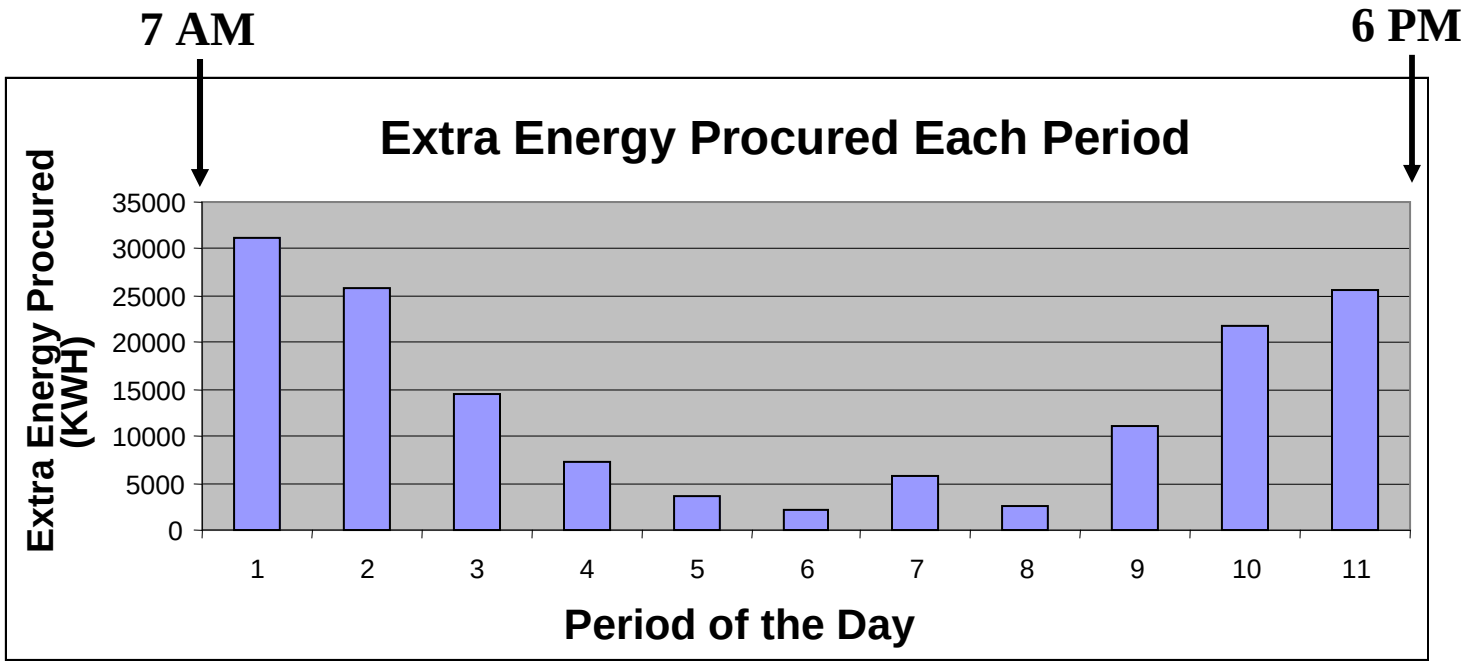
Excess Power Need (peak) ~ 5 MW

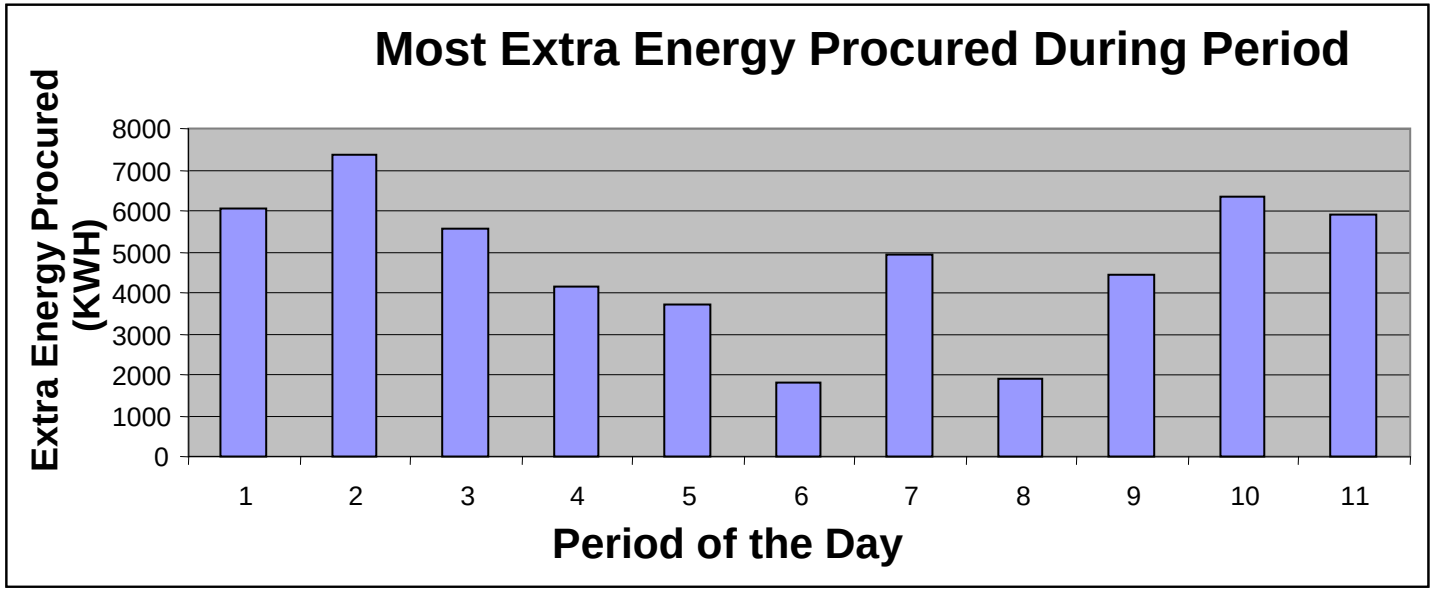
OTHER OBSERVATIONS

Number of One Hour Periods When Use Was Less than Schedule (Over Purchased) = 159

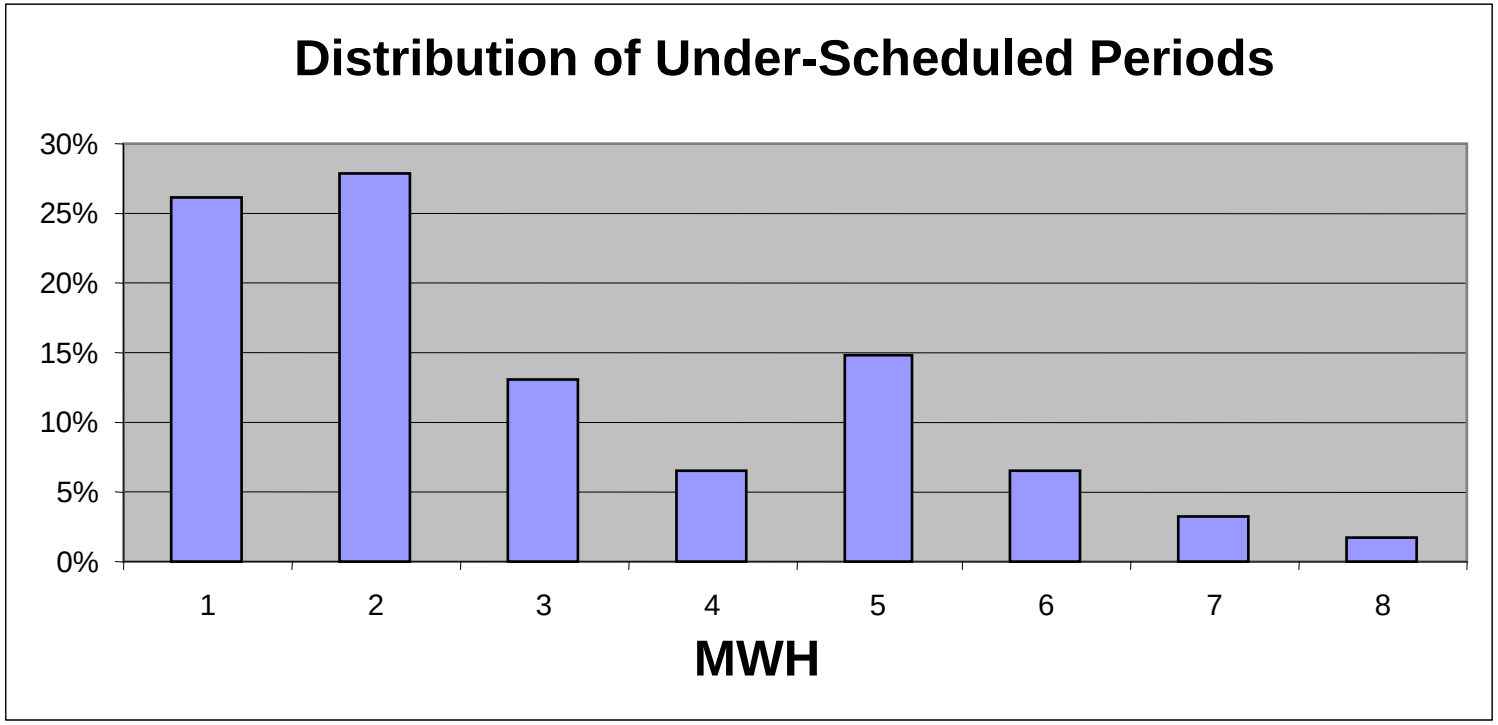
Number of One Hour Periods When Use Exceeded Schedule (Under Purchased) = 61

Ratio of Over Purchased to Under Purchased Periods ~ 2.6


7 AM
6 PM
Extra Energy Procured Each Period
Extra Energy Procured (KWH)
35000
30000
25000
20000
15000
10000
5000
0
1
2
3
4
5
6
7
8
9
10
11
Period of the Day


Most Extra Energy Procured During Period
Extra Energy Procured (KWH)
8000
7000
6000
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
Period of the Day

Distribution of Under-Scheduled Periods



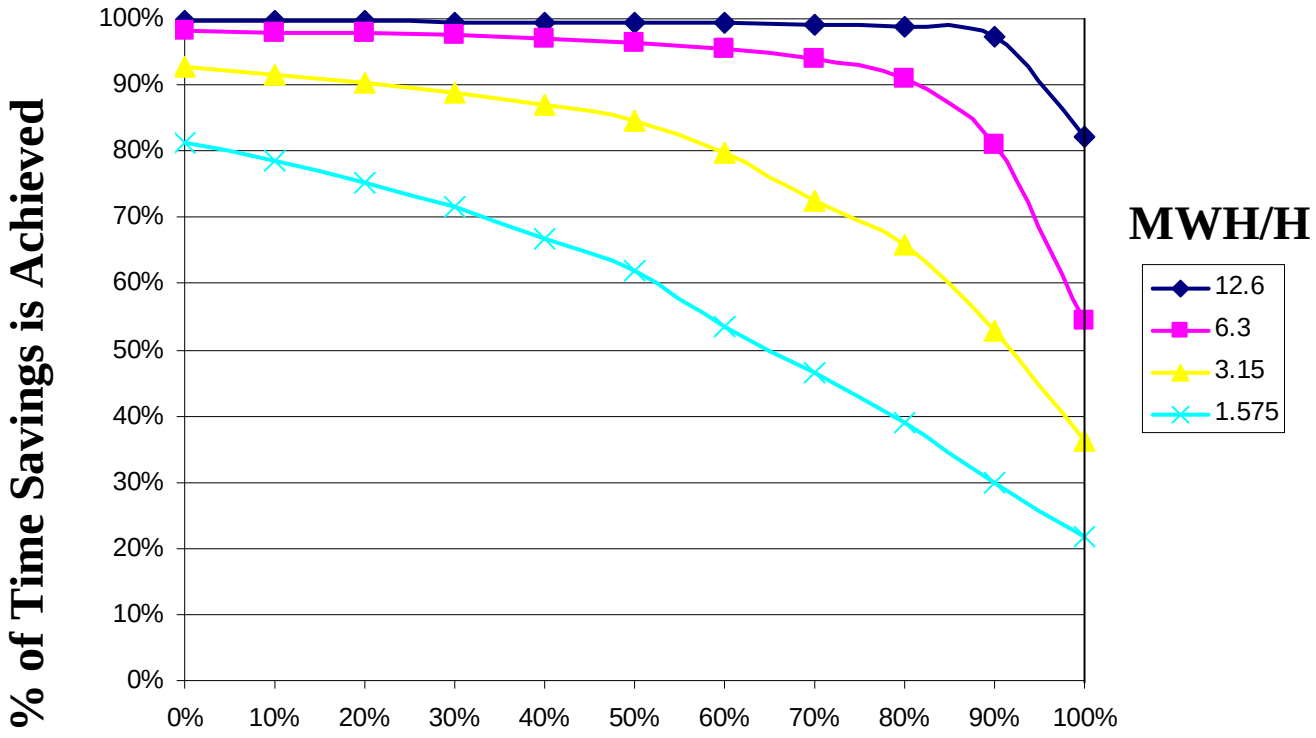
Discussion Topics

- Energy and Power Use at BART
- V2G Energy and Power Assessment
- V2G from the perspective of the car owner
- Effectiveness and Value to BART

Energy and Power Assessment for V2G at BART

- Created computer model to emulate BART's moment by moment power consumption (reference earlier graphs)
- Applied simple charge/discharge algorithm to model
- Assessed effectiveness of different levels of energy and power levels

V2G Effectiveness for Different Levels of Energy Transfer Rate (MWH / Hour) From Cars



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Commuter Model

- Commutes $D_{commute}$ each direction each weekday
- Parks in BART lot from 7 am to 6 pm (11 hours)
- One weekday evening a week, drives 10 additional miles to run errand
- Drives 250 mi/week = 13,000 mi/yr
- Weekend travel = $250 – [2 *(5*D_{commute}) + 10]$

Plug In Hybrid Car Model

Assumed Same for All Cars

- Battery capacity = 18 KWH
- Efficiency = 0.25 KWH per mile
- I.C.E. engine turns on when battery reaches an X% (X>= 20) state of charge and maintains the battery at the X% state of charge level
- I.C.E. Hybrid achieves an efficiency of 40 mpg
- Stops discharging into grid when state of charge reaches 10%
- Charges/Discharges at a maximum of P_{charge}

Energy Cost/Source Assumptions

- Electric power
  - Car charges only at the BART parking lot
  - No cost for the car owner

- Cost of gasoline is $2.80 per gallon

V2G Design Criteria

- On a typical 11 hour weekday, net energy will be added to cars for 8 hours and will be taken from cars for 3 hours (ratio of underuse to overuse hours = 2.6)

- Must allow for two consecutive hours of discharge at either end of the day
  - This requires cars to arrive with a pre-established minimum charge

Cases Examined

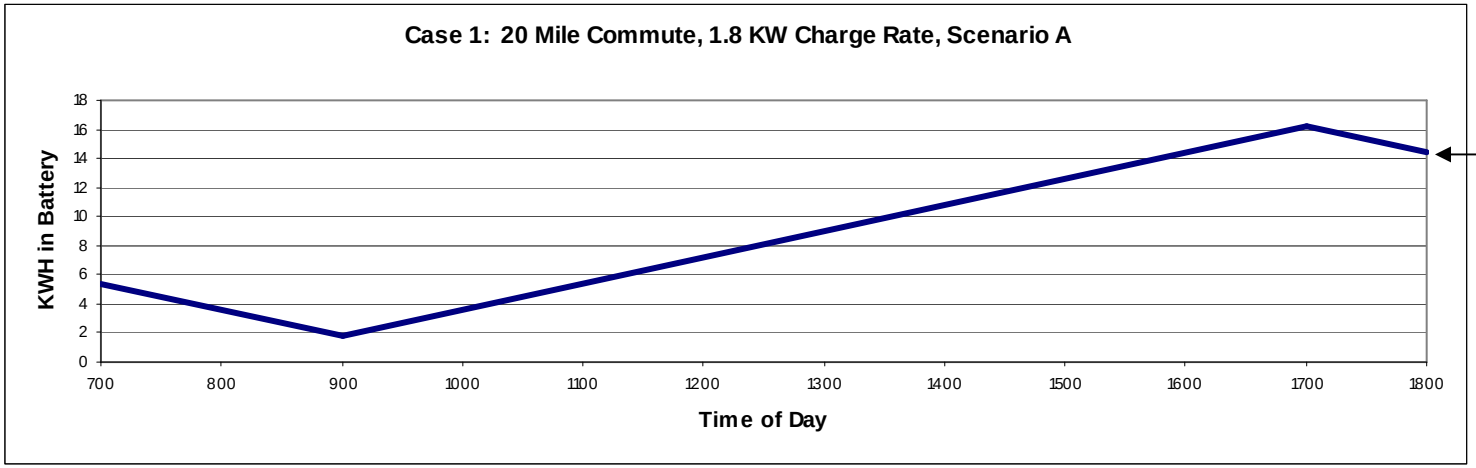
- Case 1: 20 mile commute, P_{charge} = 1.8 KW
- Case 2: 10 mile commute, P_{charge} = 1.8 KW
- Case 3: 20 mile commute, P_{charge} = 18 KW
- Case 4: 10 mile commute, P_{charge} = 18 KW

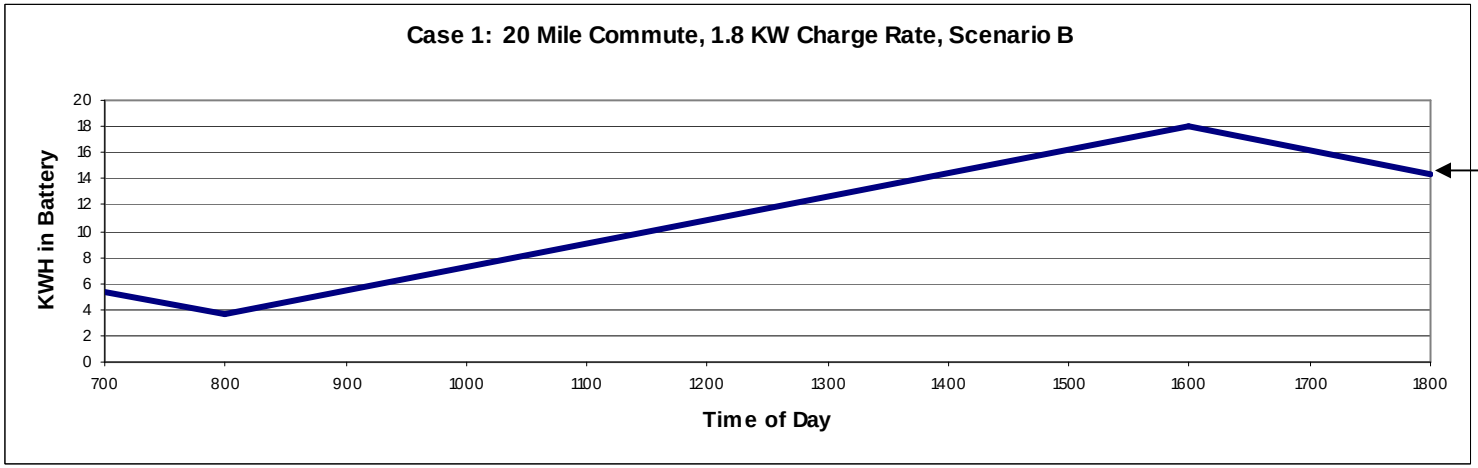
Case 1

-20 mile commute, P_{charge} = 1.8 KW -

- Car must arrive at BART on Monday with:
  - 3.6 KWH + 1.8 KWH = 5.4 KWH
- Must travel 40 miles for commute + 10 miles for errand on Monday but only 40 miles for commute the other days of the week (210 miles total)
- From Friday evening when car arrives at home until car must leave for BART on Monday the car travels an additional 40 miles (i.e. 80 miles total station to station)

CHARGE/DISCHARGE SCENARIOS
- Case 1 -





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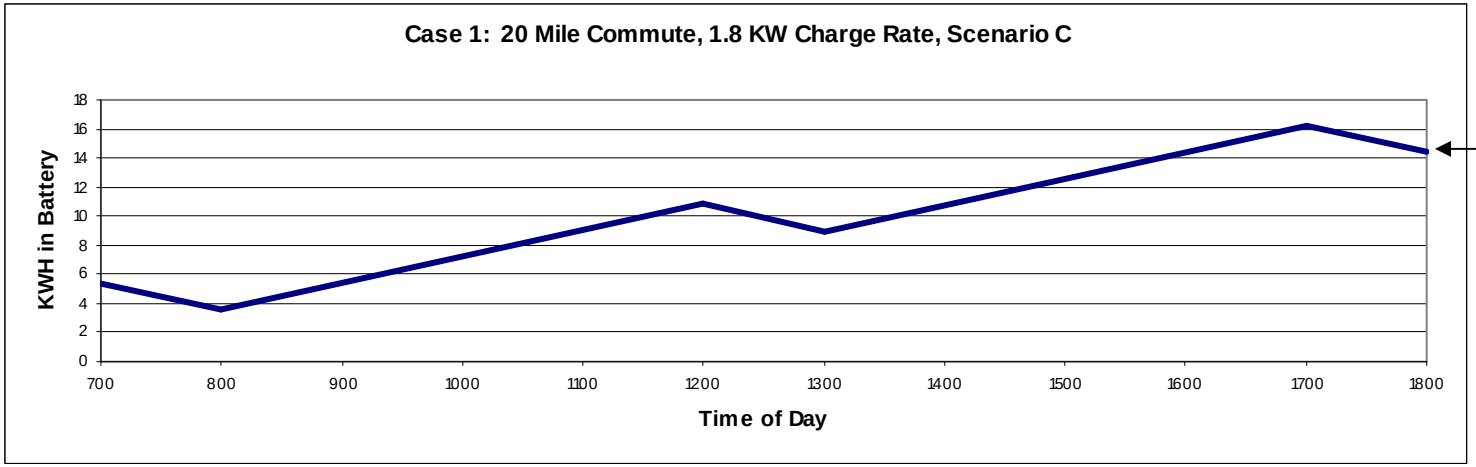
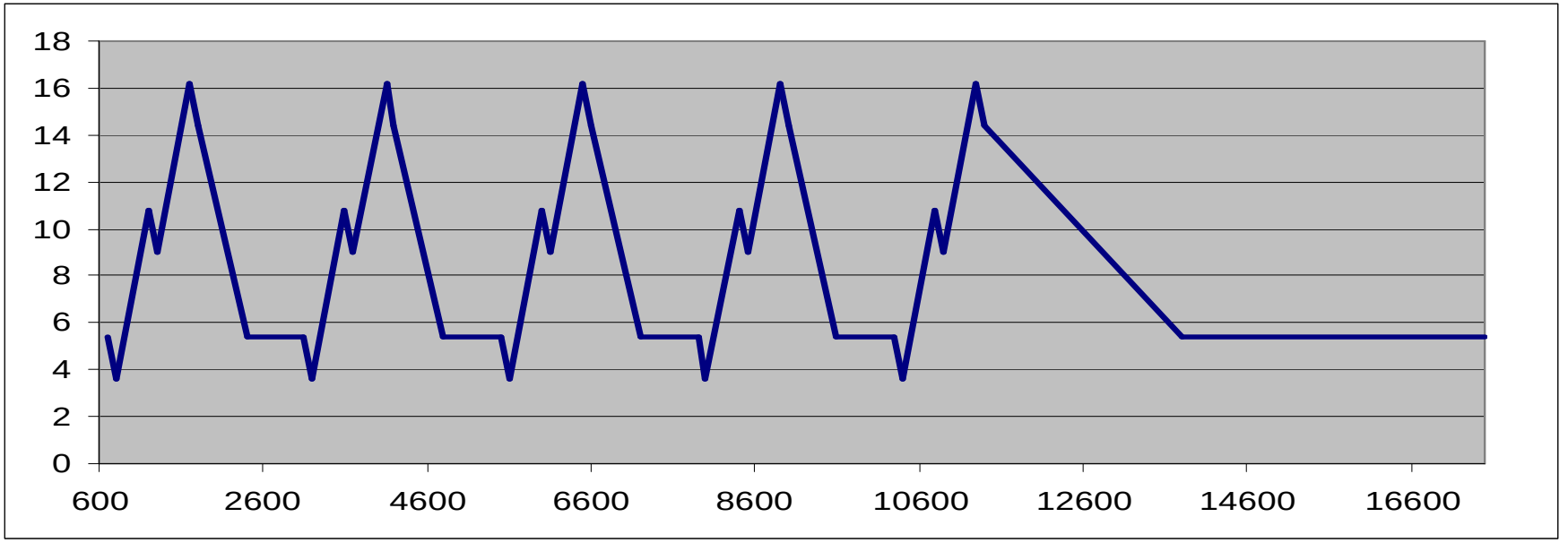


Energy in the battery at the end of the day is always 14.4 KWH

Energy Content and Cost of Gasoline During One Week
- Case 1 -

Monday **Monday**



14 miles	4 miles	4 miles	4 miles	44 miles
$0.98	$0.28	$0.28	$0.28	$3.08

TRAVEL USING GASOLINE

WITH PI HEV

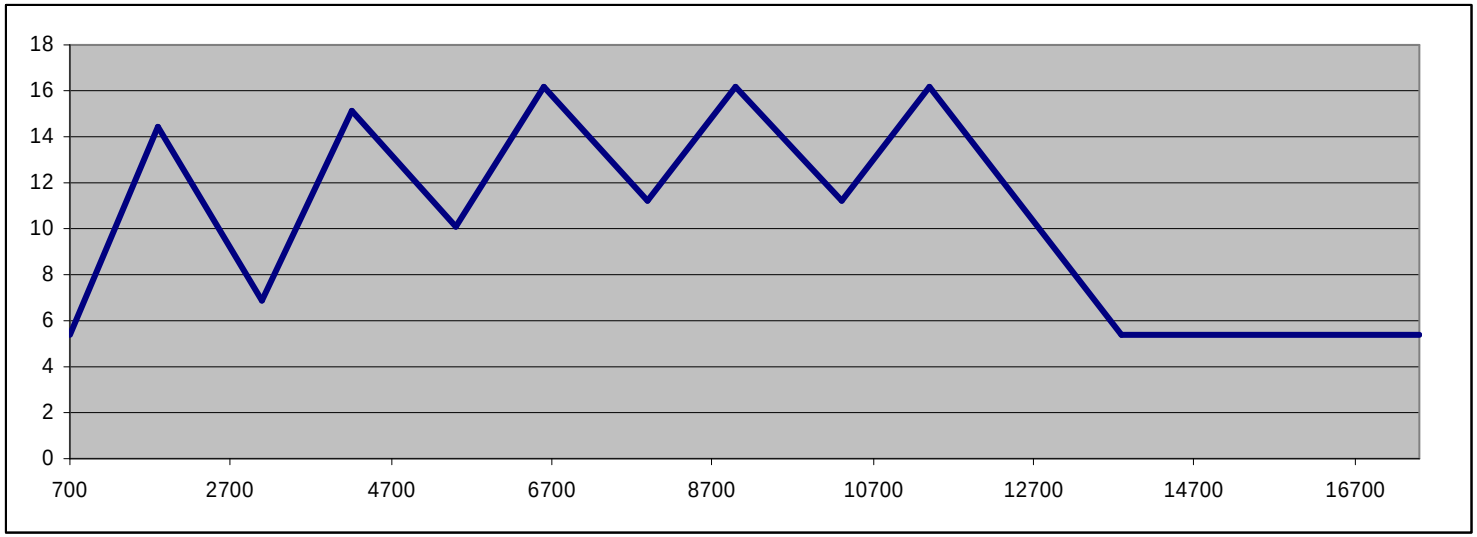
Total Gasoline Cost Per Week = $4.90
Gasoline Cost Per Year = $254
Effective mpg = 143.3 mpg

WITH I.C.E. CAR

Total Gasoline Cost Per Year = $1,456

SAVINGS PER YEAR = $1,202

Energy Content and Cost of Gasoline During One Week
- Case 2 -



116.8 mi
$8.17

WITH PI HEV

Total Gasoline Cost Per Week = $8.17

Gasoline Cost Per Year = $425

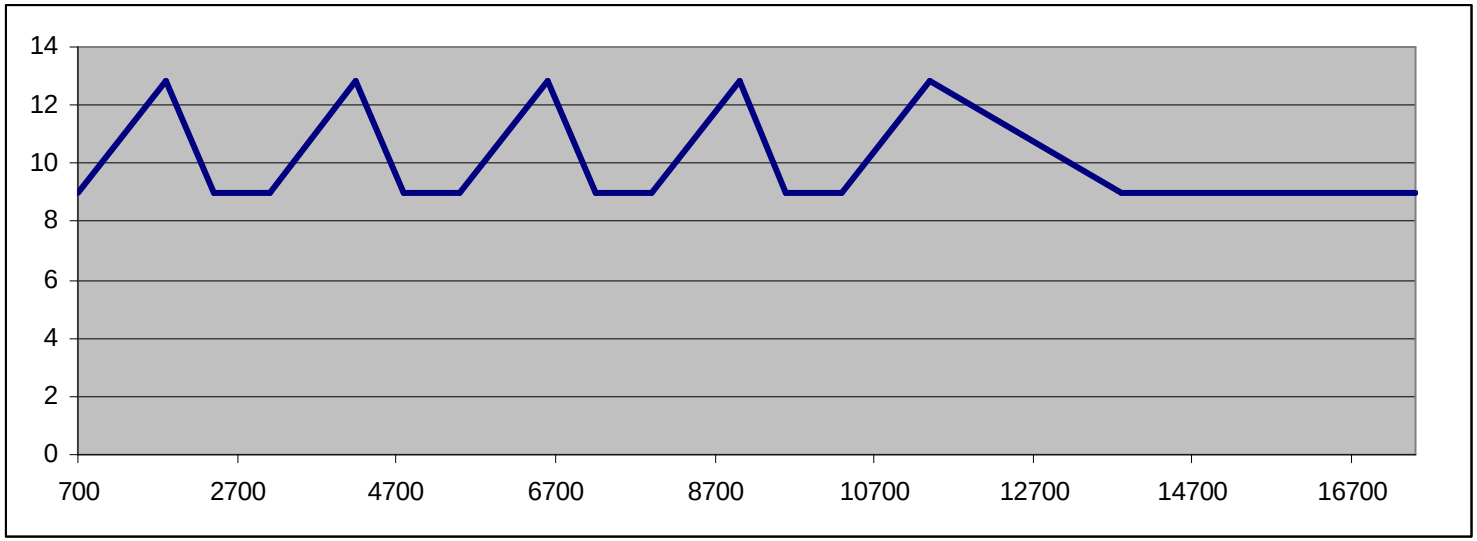
Effective mpg = 85.0 mpg

WITH I.C.E. CAR

Total Gasoline Cost Per Year = $1,456

SAVINGS PER YEAR = $1031

Energy Content and Cost of Gasoline During One Week
- Case 3 -



34.8 mi	24.8	24.8	24.8		28.8
$2.43	$1.73	$1.73	$1.73		$2.01

WITH PI HEV

Total Gasoline Cost Per Week = $9.63

Gasoline Cost Per Year = $500

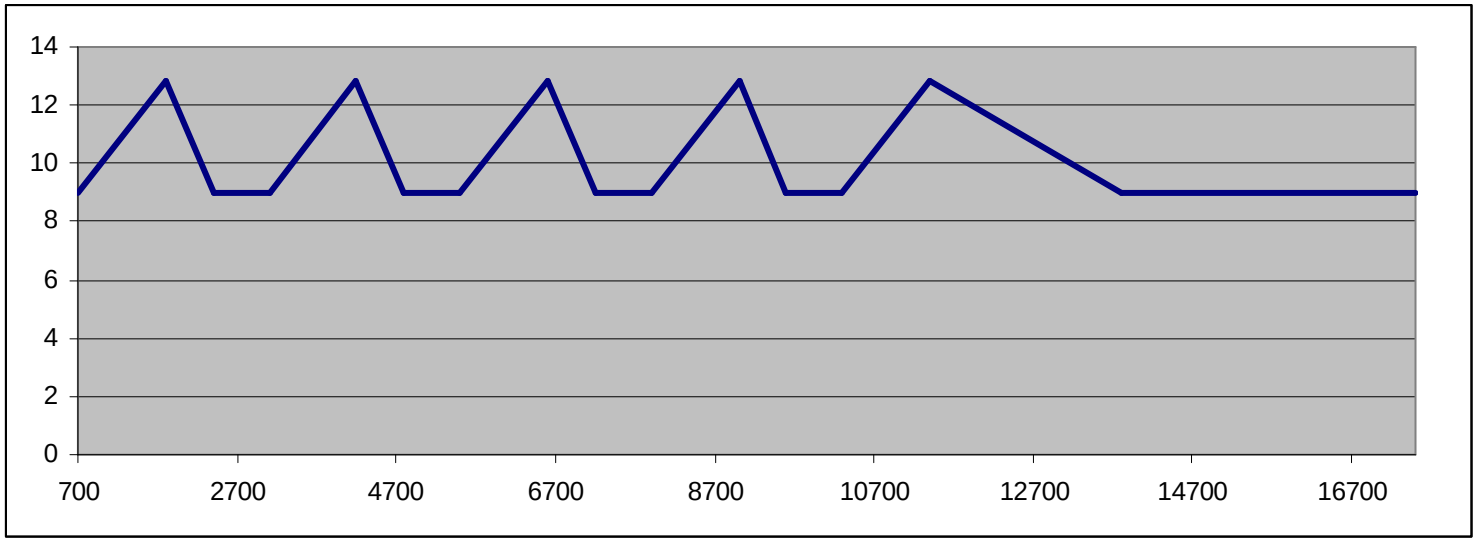
Effective mpg = 72.7 mpg

WITH I.C.E. CAR

Total Gasoline Cost Per Year = $1,456

SAVINGS PER YEAR = $956

Energy Content and Cost of Gasoline During One Week
- Case 4 -



14.8 mi $1.03	4.8 $0.34	4.8 $0.34	4.8 $0.34		144.8 $10.13

WITH PI HEV

Total Gasoline Cost Per Week = $12.18

Gasoline Cost Per Year = $633.36

Effective mpg = 57.5 mpg

WITH I.C.E. CAR

Total Gasoline Cost Per Year = $1,456

SAVINGS PER YEAR = $823

Summary Table

	Energy Transfer Rate (KWH per Hour)	Yearly Savings for Car Owner	Effective Miles Per Gallon Achieved
Case 1: 20 mile commute, 1.8 KW Charger	**1.8 KWH**	**$1,202**	**143.3 mpg**
Case 2: 20 mile commute, 1.8 KW Charger	**1.8 WH**	**$1,031**	**85.0 mpg**
Case 3: 20 mile commute, 18 KW Charger	**3.6 KWH** **1.8 KWH**	**$956** **$1,202**	**72.7 mpg** **143.3 mpg**
Case 4: 10 mile commute, 18 KW Charger	**3.6 KWH** **1.8 KWH**	**$823** **$1,031**	**57.5 mpg** **85.0 mpg**

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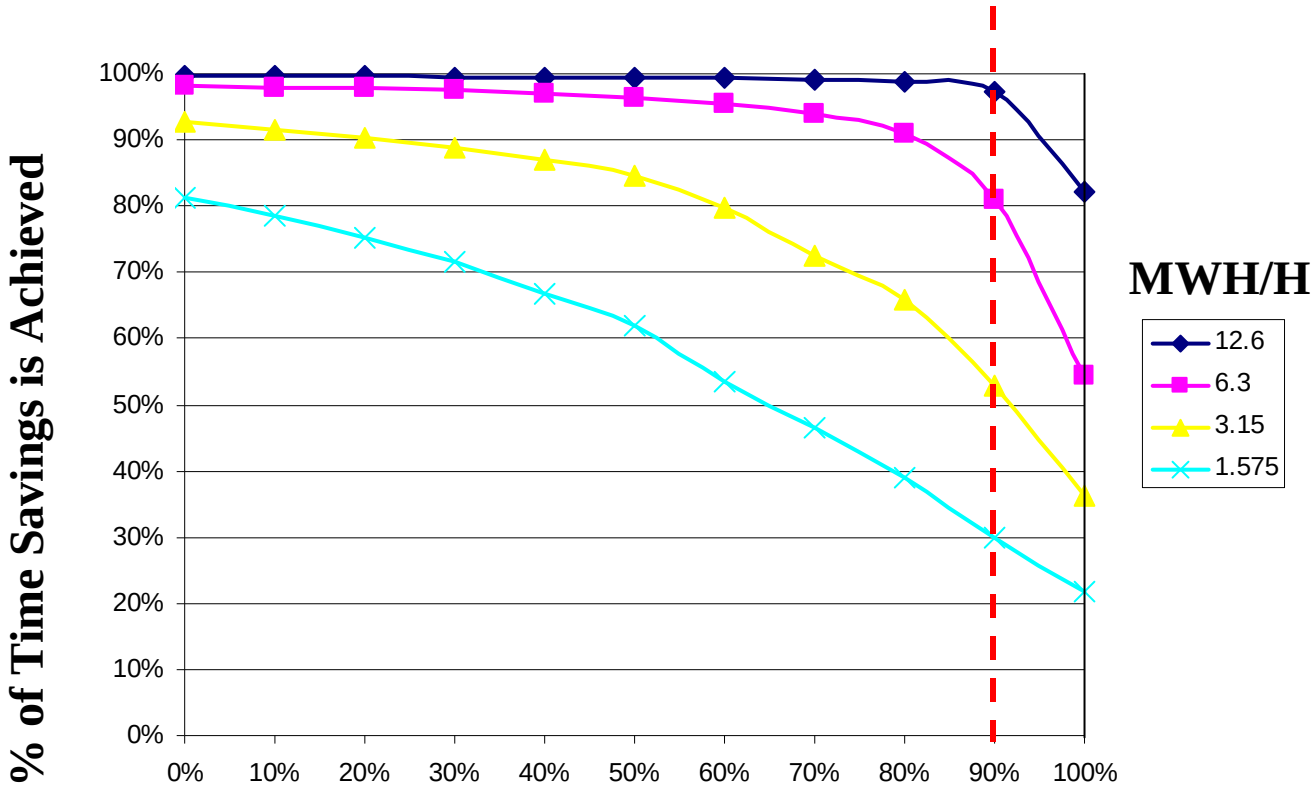
V2G Effectiveness for Different Levels of Energy Transfer Rate (MWH / Hour) From Cars



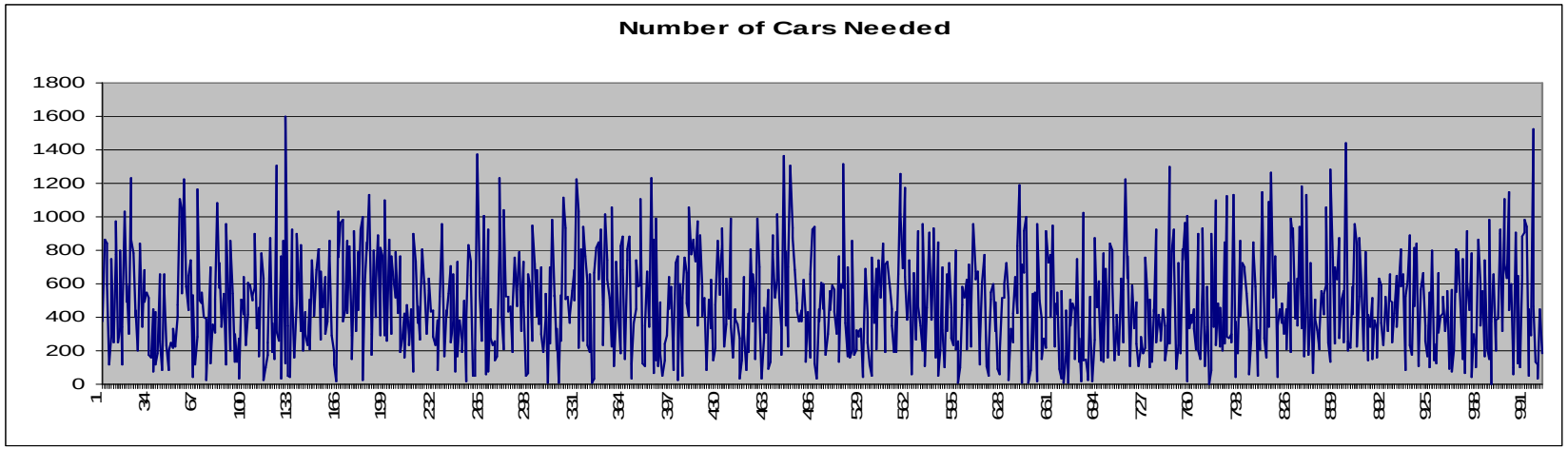
HOW MANY CARS?

For 1.8 KW Charger

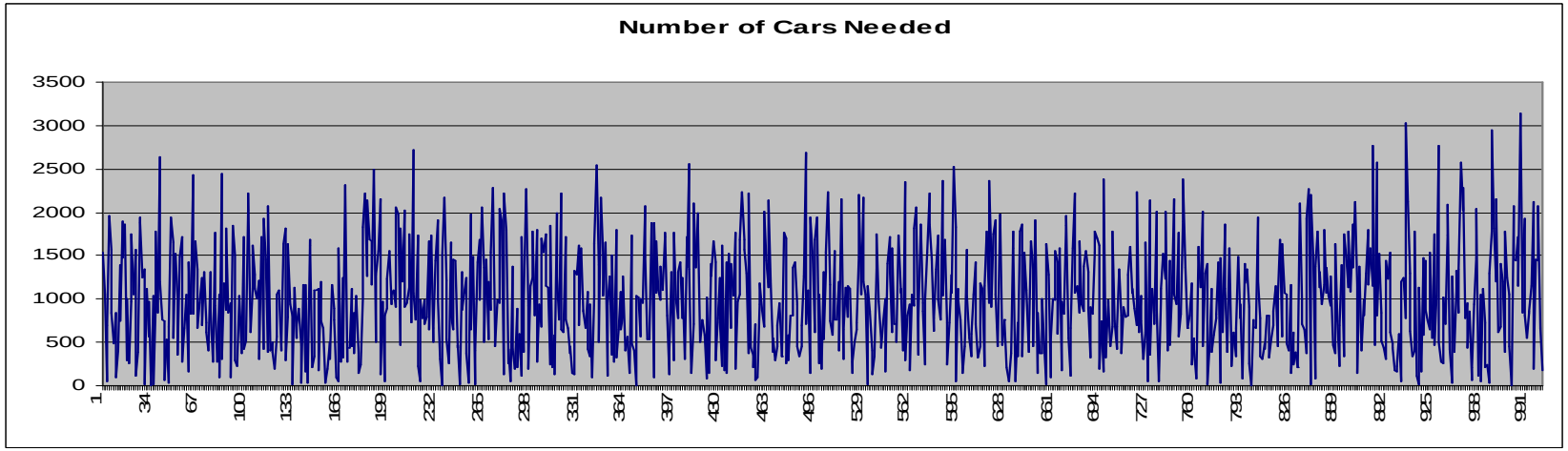
6.3 MWH / 1.8 KWH = 3,500 Cars

For 18 KW Charger

3.6 KWH Per Hour



1.8 KWH Per Hour



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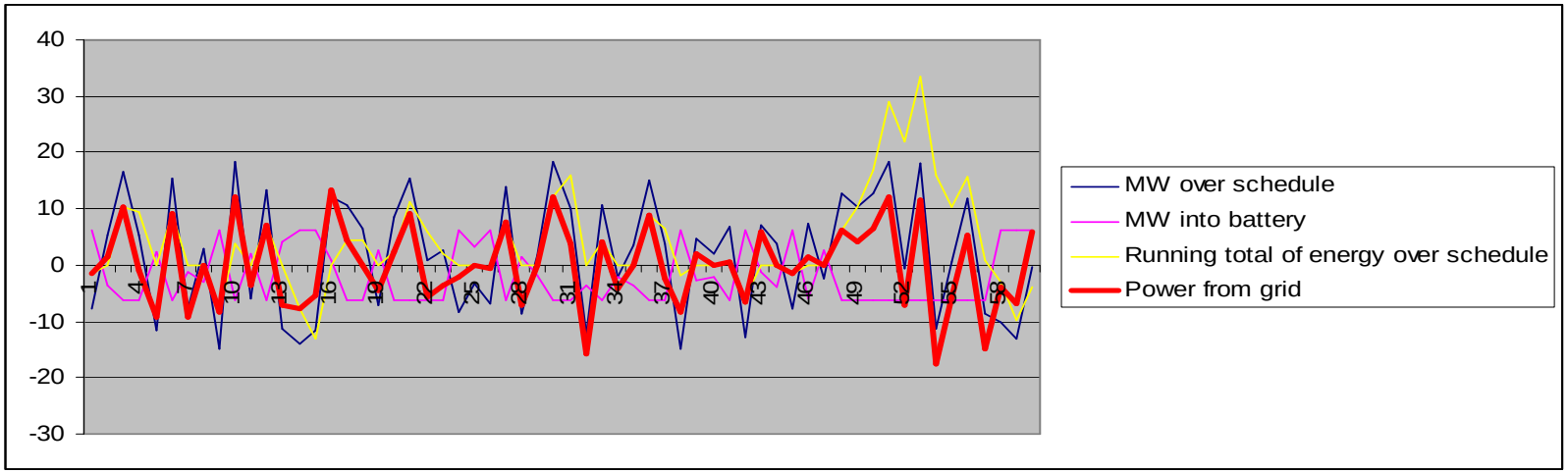
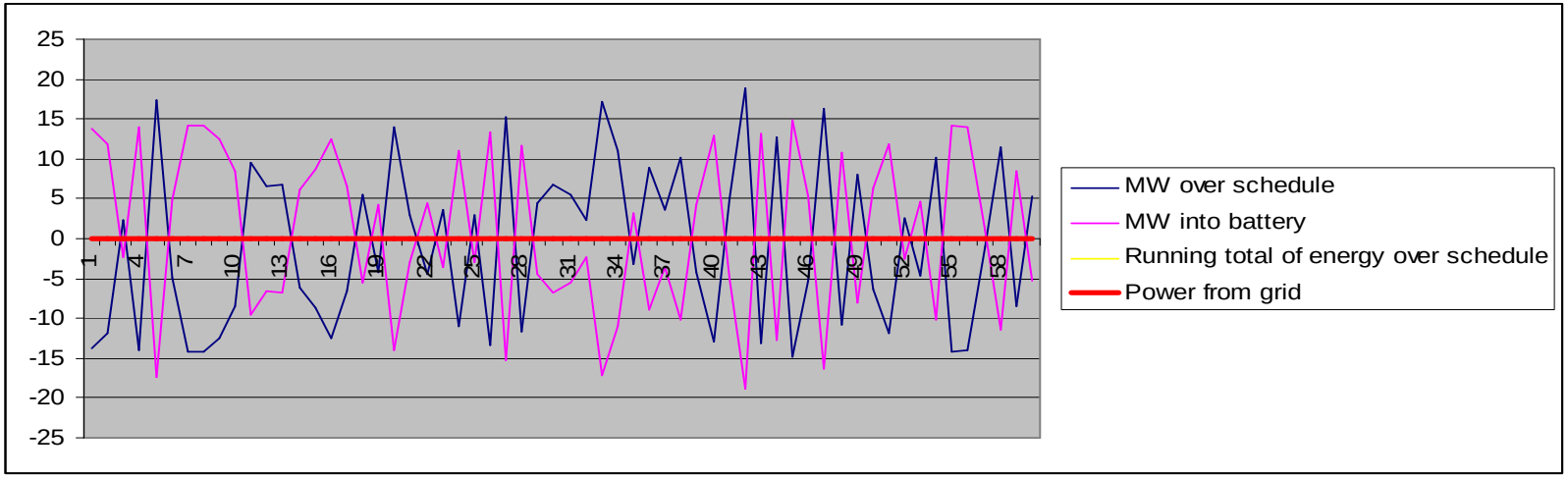
Case 3: 20 mile commute, 18 KW Charger	3.6 1.8	$956 $1,202	72.7 mpg 143.3 mpg	~ 1,400 Cars
Case 4: 10 mile commute, 18 KW Charger	3.6 1.8	$823 $1,031	57.5 mpg 85.0 mpg	~ 2,500 Cars

POWER MANAGEMENT

3500 Cars at 1.8 KW Chargers

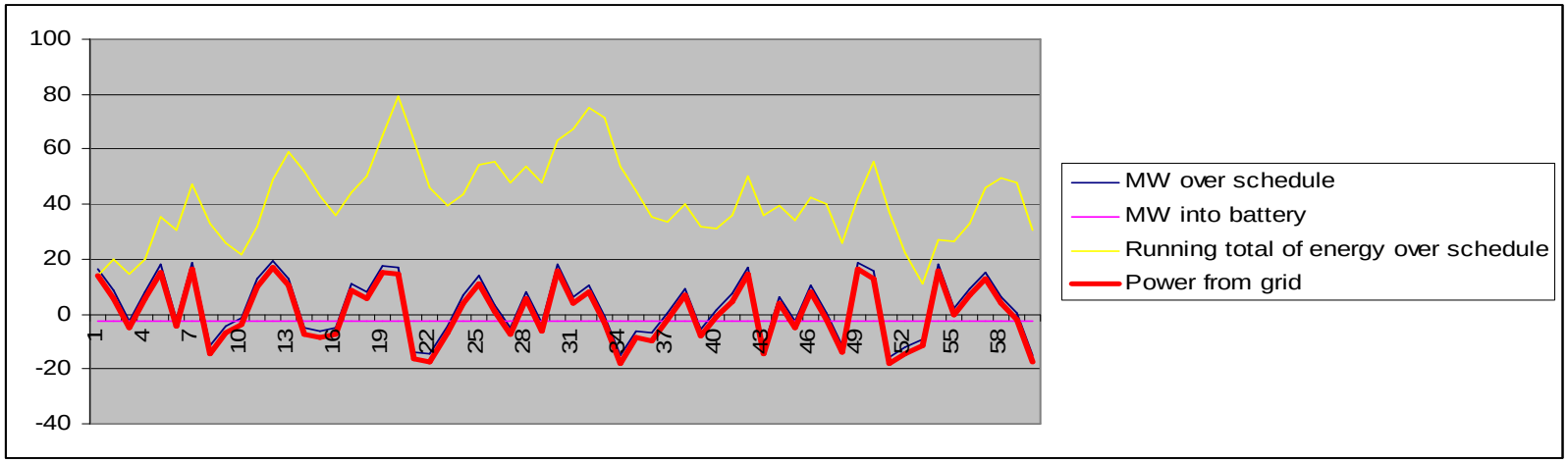


3500 Cars at 18 KW Chargers (Limited to 3.6 KWH/H)

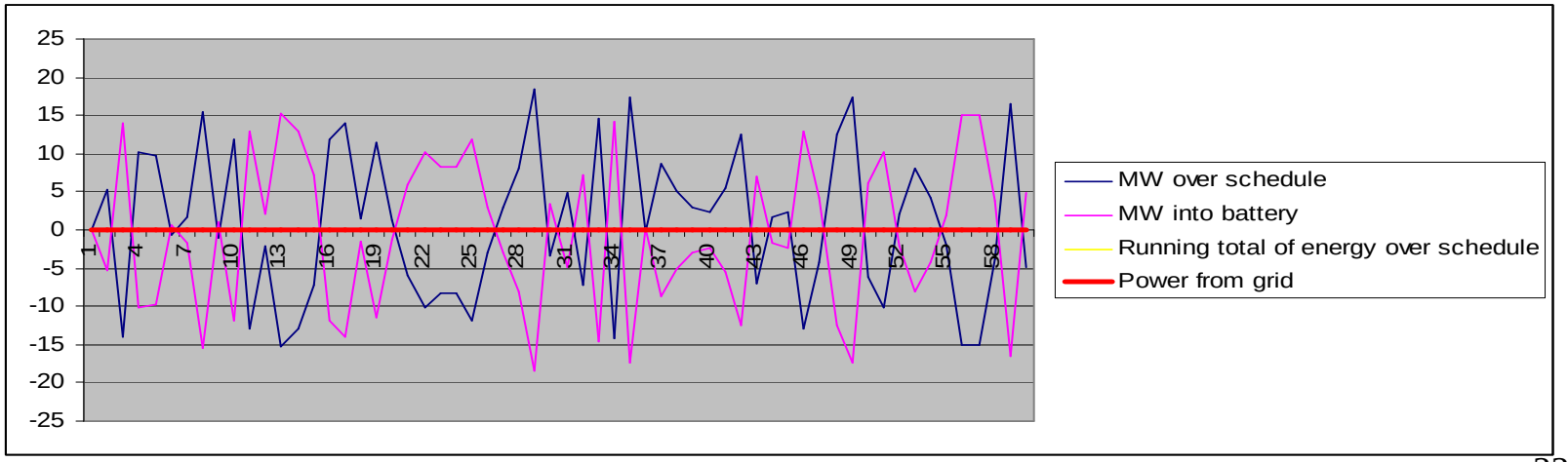


POWER MANAGEMENT

1400 Cars at 1.8 KW Chargers



1400 Cars at 18 KW Chargers (limited to 3.6 KWH/H)



Value to BART

- Energy purchased in excess of schedule between 7 am and 6 pm on weekdays = 151.6 MWH
- 151.6 MWH at $0.20 per KWH = $30,320
- 72% reduction in overcharges = $21,830
- Yearly savings ~ 12 x $21,830
  ~ $261,964

Closing Thoughts

Conclusions

- Value to justify PI HEV ownership will be in the range of ~$1,000 per year if charging is provided free of charge
- Value to BART today might be in the range of about $260,000 per year from a reduction in extra energy purchases
- Business model needs to consider cost of different charging hardware and policy regarding cost of energy

Example Business Case

- At $1,000 per charging station, 1,400 stations would cost $1.4 million
- At a savings of $261K per year, payback would take 5+ years
- If energy charges were levied such that 30% of the savings to car owners was charged as a fee, a revenue stream of $420 K would accrue to BART
- Pay back in this case might be in as short as 2 + years

Demonstration Proposal

- The concept of V2G as a viable concept needs a kick-start
- Privately owned hybrid cars exist in large numbers but cars require retrofit ($5 to $10 K) to become plug-in capable
- With funding to current and future car owners for retrofit kits and to BART for charging stations there is an opportunity to demonstrate viability and business case for V2G vehicles

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